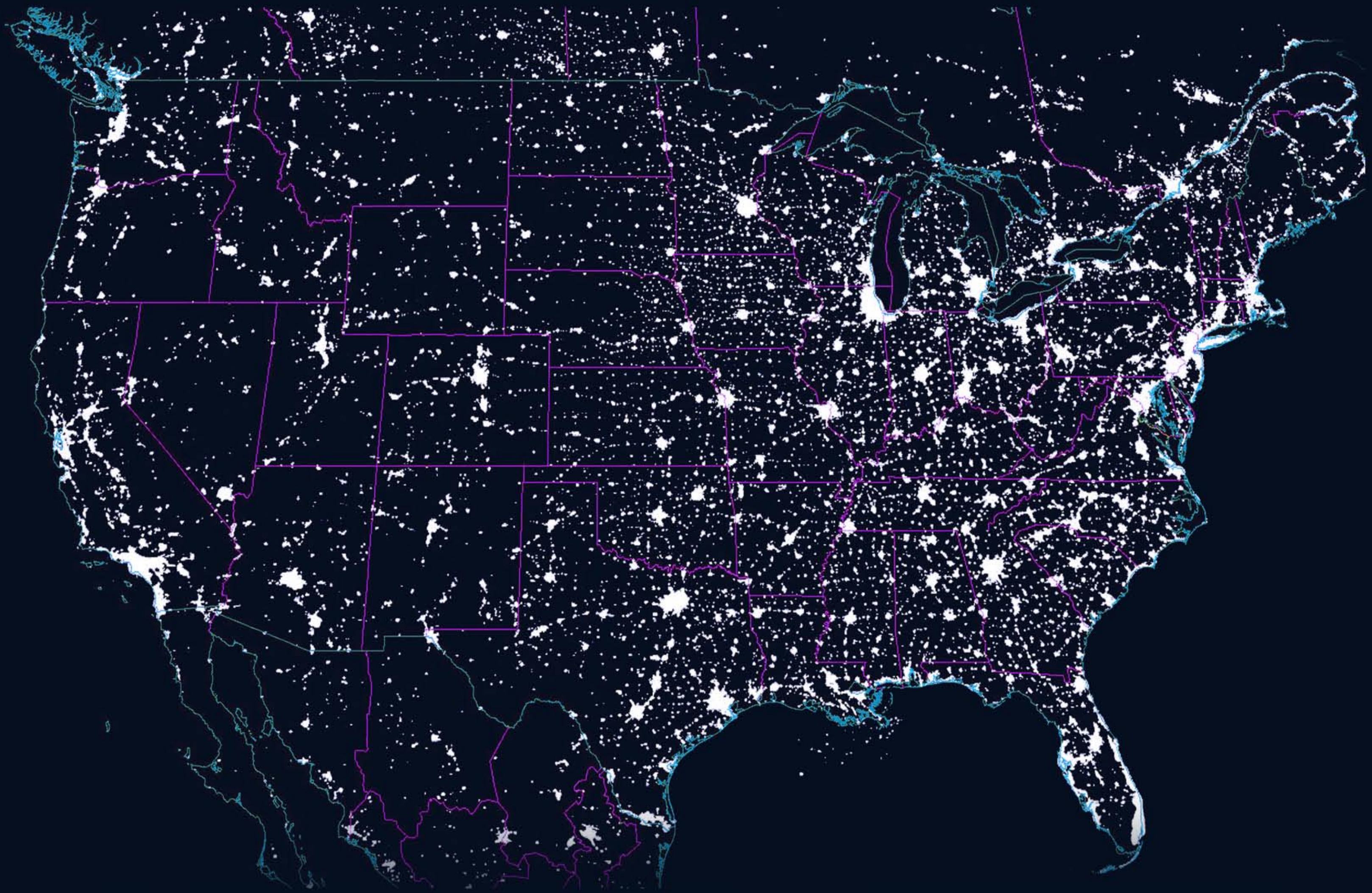

INFRASTRUCTURE

Energy and Environment Compendium

Los Alamos
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INFRASTRUCTURE

Energy and Environment Compendium

This book is part of Los Alamos National Laboratory's Energy and Environment Compendium series. Other books in this series:

CARBON
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Infrastructure Research at Los Alamos National Laboratory

Los Alamos National Laboratory performs basic and applied research to secure the nation's energy infrastructure. Central to this research is the development of large-scale, detailed computer models of energy industries and other infrastructures. Such work requires close cooperation with physicists, engineers, mathematicians, statisticians, computer scientists, and economists. Our macro models and micro simulations aim to quantify the physical, operational, and economic behavior of energy networks (electric power, natural gas, oil, and coal generation/transmission/distribution) and non-energy infrastructures important to energy security (transportation, water, communications, and public health). Often these models are combined within interdependency, optimization, and risk assessment frameworks.

Current Research Activities

Los Alamos is developing and testing new technologies for the next generation of electrical grids. These new technologies will require integration into a complete architecture including hardware solutions as well as modeling, simulation, and data analysis. The new programs supporting the next generation electrical grid must sense the health of the grid and input this data into the models and tools under development. The Laboratory is participating in the governance of DOE's Energy Infrastructure Training and Analysis Center (EITAC) through a steering group that includes Sandia and Argonne national laboratories. The first EITAC visualization capabilities will be Los Alamos products.

Current Research and Development Challenges

- Development of robustness metrics when multiple infrastructures are mutually dependent;
- Models and simulations that predict and visualize energy outages based on loss of critical components;
- Communication protocols and data aggregation techniques to support a real time visualization and forecasting capability;
- Analysis of emerging technologies that could be applied to the national electric power grid to help minimize large scale outages (would be used to help determine specifications and investment priorities for future technologies);
- Development of tools to perform real-time, short-term dynamic analysis of the national electric power grid; and
- Development and application of technologies, such as high temperature superconductors, to reduce or eliminate the present bottlenecks in the electric power system.

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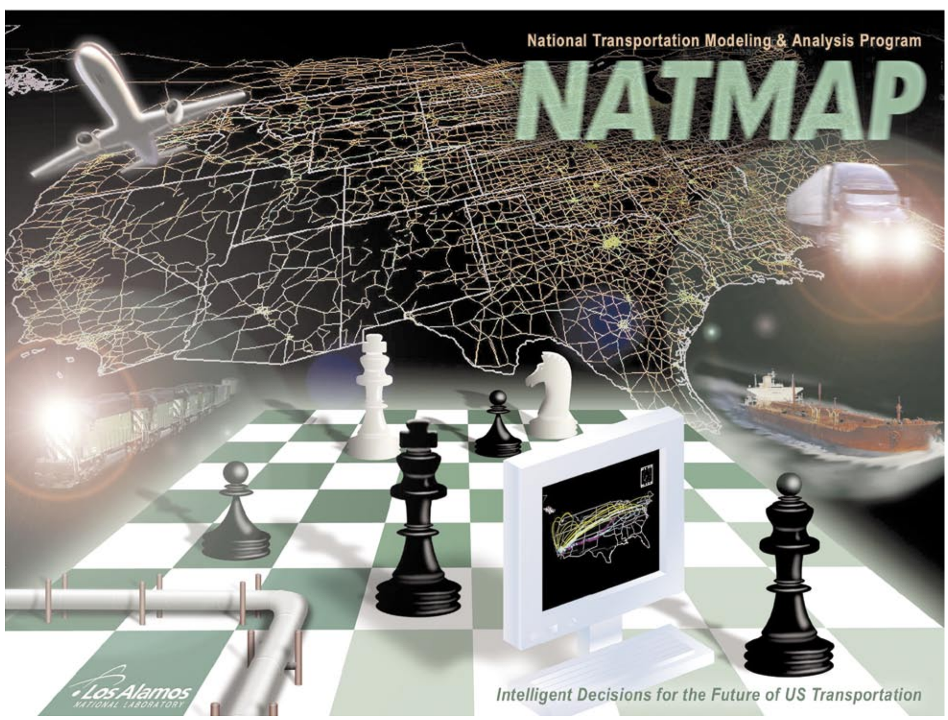
National Transportation Modeling and Analysis Program

The Challenge: Simulating Transportation of Commodities

Our nation's fossil energy infrastructure is highly dependent on the transportation infrastructure. Without the shipping, trucking, pipelines, and rail systems that move fossil fuels, the U.S. energy system would come to a halt. The National Transportation Modeling and Analysis Program (NATMAP), currently under development at Los Alamos under the sponsorship of the Department of Transportation, is simulating the many modes of the national transportation system to understand their dependencies and vulnerabilities. NATMAP models the transportation network down to the fine detail of individual carriers—such as trucks, trains, planes, waterborne vessels, and pipelines—to simulate commodity shipments across the U.S. infrastructure. It also simulates the movement of individual freight shipments from production areas through intermodal transfer facilities and distribution centers to points of consumption.

Los Alamos Innovation: Making Detailed Representations of Traffic Flows at Many Different Levels

Unlike traditional, static models that can only model transportation and flows at gross levels, NATMAP employs dynamic, “bottom-up,” disaggregated modeling techniques. The advantage of this individual carrier/shipment simulation approach is in the level of detail in which the nation’s fossil fuel transportation system can be represented, from trucks and goods moving among counties and within regions, to national multi-modal traffic flows including cross-border trade with Mexico and Canada. This strength can be exploited for transportation policy and for security and infrastructure investment purposes.



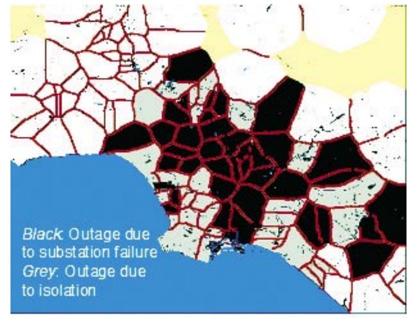
The Impact: An Efficient and Secure Transportation Infrastructure

Initial deployment will focus on real-world issues defined by the Department of Transportation and other stakeholders, thus enabling intelligent decisions that will ensure the future efficiency, reliability, and security of the transportation infrastructure and the economy it supports.

Electric Power Grid Modeling

The Challenge: Securing the Energy Infrastructure of the United States

Los Alamos National Laboratory researchers have long investigated energy generation and transmission networks to help various federal, state, and local agencies to understand these infrastructures, track their evolution, identify their strengths and weaknesses, assess their reliability, and analyze their economics. With extensive databases, tools, and expertise, the Laboratory has taken a two-pronged approach to studying electric grid reliability: (1) the effects of electric power industry deregulation and mergers; and (2) the effects of natural disasters on the energy infrastructure of the United States.



Projected (simulated) electrical outage in the Los Angeles area due to Earthquake damage.

Los Alamos Innovation: Simulating Economic and Physical System Connections

Los Alamos has made innovative simulations of the interdependencies between energy infrastructures and deregulated energy markets in an attempt to better understand market structure influence on day-to-day systems operation. The Laboratory has also evaluated air quality and economic tradeoffs between centralized and dispersed electric generation plants. State-of-the-art power flow simulation tools are used to identify:

- Service and outage areas,
- Outage duration,
- Critical system components,
- Restoration strategies,
- Mitigation options, and
- System performance.

These analyses determine the electric grid's ability to meet electrical demand and energy requirements. Los Alamos has developed a unique, in-depth capability to collect the required data, build and verify accuracy of infrastructure models, and integrate these into databases describing the national infrastructure. From urgent case studies to long-term research projects, work has been coordinated with other national laboratories, industry, and government agencies.

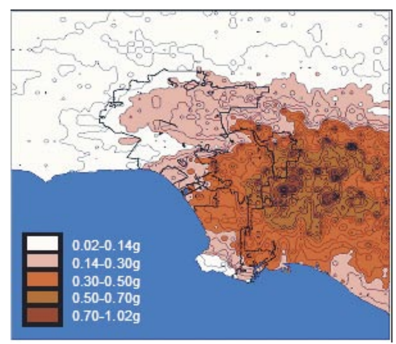


Illustration of damage estimate, based on previously estimated ground motion, for a simulation scenario.

The Impact: A More Reliable Power Infrastructure

The main goal of this research activity is to identify outage events that impact electric power supply reliability, develop vulnerability mitigation options, and create business continuity strategies. By foreseeing potential vulnerabilities caused by market changes or natural disasters, potential problems can be addressed before they interfere with the nation's economy and quality of life.

Interdependent Energy Simulation System

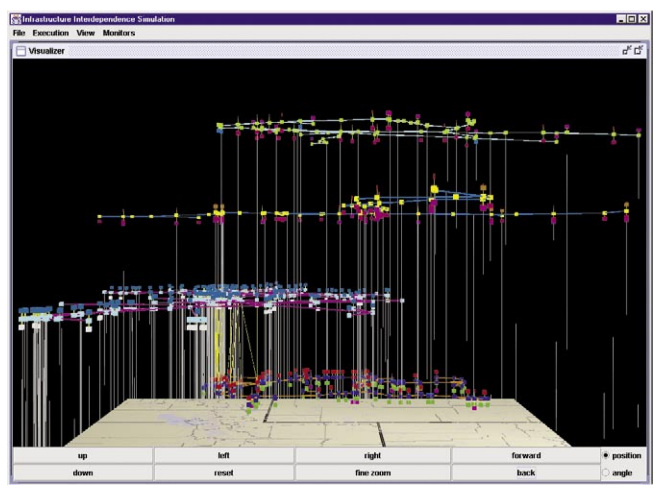
The Challenge: Understanding System Interdependencies

The nation's security requires that the interdependent energy, communication, and transportation infrastructures provide an appropriate quality of dependable service. Each of these infrastructures consists of many interlinked subsystems. To accurately simulate the nation's energy infrastructure, Los Alamos National Laboratory has expanded its efforts in electric power grid security to include energy the generation and transmission subsystems. We have modeled natural gas pipeline networks and petroleum liquid networks and also plan to model the U.S. coal infrastructure. Energy infrastructures typically have “feedback loops,” where infrastructures depend upon each other to deliver their products. For example, a gas-fired electric generating plant requires a steady supply of natural gas, and the natural gas pipelines may require electric-powered compressors to maintain sufficient pressure. The interdependency concept is critical to understanding these complex coupled systems, and an inflexible modeling and technology base has hampered the understanding of them in the past.

Los Alamos Innovation: Coupled Models of Complex Infrastructures

The Interdependent Energy Infrastructure Simulation System (IEISS), embodied as analysis software tools developed at Los Alamos in collaboration with Argonne National Laboratory, aims to develop a comprehensive simulation study of the nation’s interdependent energy infrastructures to address a wide variety of intra- and inter-infrastructure dependency questions. This capability allows the Laboratory to identify and understand infrastructure interdependencies during normal operations and disruptions and provides the ability to assess the technical, economic, and national security implications of system configurations. This will enable a detailed analysis and understanding of entire interdependent infrastructures, including their components and couplings, in a manner far beyond what could be done previously.

A prototype version of IEISS was used in preparation for the 2002 Salt Lake City Olympics. This figure overlays major energy infrastructure networks on a map of key Olympic sites. Vertical lines identify system interdependencies.



The Impact: Avoiding Crises by Identifying Weaknesses

Los Alamos envisions diverse applications for analyses based on IEISS. The ability to identify critical components and vulnerabilities in coupled infrastructure systems will allow us to (1) assess how future investments in the systems might affect quality of service; (2) perform integrated cost-benefit studies; (3) evaluate the effects of regulatory policies; and (4) aid in decision-making during crises.

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Urban Security

The Challenge: Protecting Cities

Recognizing the importance of understanding the social, economic, infrastructure, and environmental components of cities in an integrated manner, Los Alamos National Laboratory began work on the Urban Security project. The majority of the world's population now resides in cities that are increasingly the foci for epidemics, warfare, and terrorism. Large cities are places where infrastructure and environment meet humanity, creating a situation ripe for natural disasters of grand scale, as well as human-made disasters that often result from poor long-term planning decisions.

Los Alamos Innovation: Coupling Human, Engineered, and Environmental Systems

Using the broad spectrum of disciplines and computing capabilities at Los Alamos, the Urban Security project examines the links between human society, the economy, infrastructures, and the environment. By working collaboratively across the physical and social sciences to more fully understand human, engineered, and natural systems, we can more effectively prepare for natural disasters through hazard mapping, natural process modeling, and crisis forecasting and planning. New tools will be developed for long-range urban planning, and vulnerability to terrorism or large-scale mischief will be identified.

The Impact: Safer, Well-Managed Cities

The 21st century will call for the increasing collaboration of physical and biological scientists with social scientists, economists, and infrastructure engineers. With the existing expertise to fully develop an urban science mission, the interdisciplinary and interdivisional spirit of the Laboratory could be used to research and develop homeland security solutions and to address urban planning problems such as the effects of natural hazards, uncontrolled urban growth, unstable bureaucracies, environmental security, and cost-effective urban planning. Research and development can result in new approaches to city planning, management, and decision-making, and tools can be developed to monitor change. Finally, virtual training environments can be developed for city managers, emergency responders, and utilities engineers.

Lower Manhattan following the terrorist attacks on 9/11/2001.

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Urban Dispersion Modeling of Airborne Chemical and Biological Agent Threats

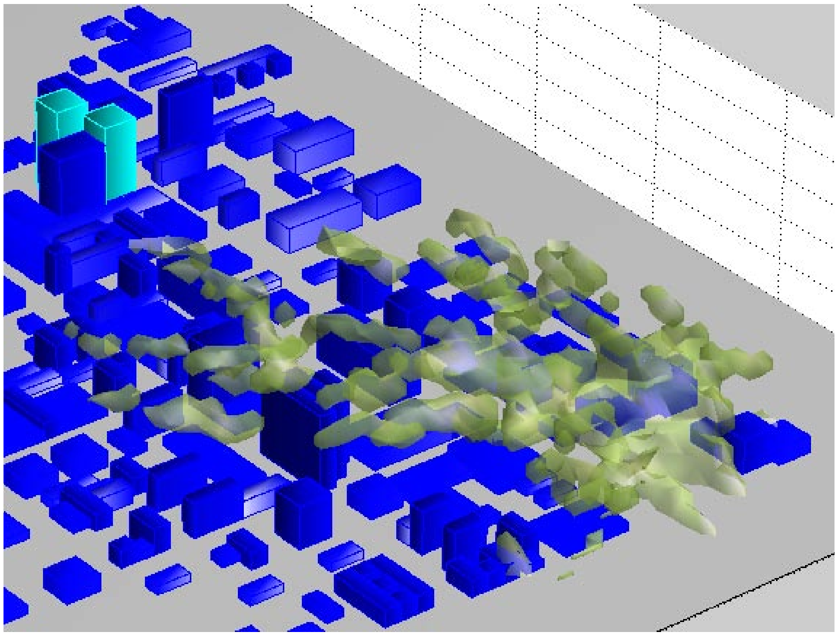
The Challenge: Responding to Chemical and Biological Terrorism

Because one possible terrorist attack scenario involves the release of Chemical or Biological (CB) agents in a city, Los Alamos National Laboratory has been working on urban plume transport and dispersion modeling under the DOE Chemical and Biological National Security Program (CBNP), and the Department of Homeland Security. Most dispersion models currently in use for emergency response applications take little or no account of the urban setting. Without incorporating the presence of buildings, the dispersion of a CB agent released in an urban area is difficult to predict.

Los Alamos Innovation: Developing Fast Response Models For Use in Cities

To simulate the transport and dispersion of a CB agent in urban areas, Los Alamos is developing fast response models that will compute the three-dimensional wind patterns and dispersion of airborne contaminants around clusters of buildings. These types of models are essential for vulnerability assessment studies where many cases must be simulated in a limited amount of time or where an answer is needed quickly. The Quick Urban & Industrial Complex (QUIC) fast-response urban dispersion modeling system includes the QWIC-URB wind model and the QWIC-PLUME dispersion model. In addition, a hybrid engineering and meteorological computational fluid dynamics model called HIGRAD is being used for high-fidelity applications. These codes are intended to

- Formulate scenarios for tabletop exercises;
- Plan strategies for coping with emergencies at special events; and
- Develop vulnerability analyses and mitigation strategies for specific sites.



Simulation of a chemical or biological agent dispersion through downtown Salt Lake City using the QUIC dispersion modeling system. Calculations took approximately 5 minutes on a PC laptop.

The Impact: Being Prepared for Real-World Emergencies

Models developed for this project have already been applied to real-world scenarios. They have contributed to three important homeland defense programs—the National Biological Defense Initiative, the Biological Aerosol Sentry Information System, and Project BioWatch. Vulnerability assessments of government facilities after 9/11 have been carried out as well as vulnerability assessments for the Safety Division at Los Alamos. The program has also contributed to the development of a guide, the "Emergency Responder's Rules-of-Thumb for Toxic Airborne Releases in Cities," that has been distributed by FEMA, incorporated into police training courses, and used by fire chiefs and state agencies.

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Elecnet

The Challenge: Preventing Power Outages and Electrical Accidents

As we have become more and more reliant on electrical power, demand continues to increase beyond the infrastructure's capacity to supply, and power outages are commonplace. Annual losses caused by power outages total in the billions of dollars. In addition to outages, power efficiencies are much lower than they could be, resulting in waste and higher costs for electricity.

Beyond monetary losses resulting from problems with electrical power reliability and efficiency, there is the issue of human safety. A huge percentage of annual fires, property losses, deaths, and injuries, can be attributed to electrical accidents.

Los Alamos Innovation: Elecnet's Intelligent Sensors that Detect and Prevent Problems

ElecNet (i.e. Electrical Network), is a smart, secure networked system that can monitor important electrical and security data in real time. ElecNet is easily scalable and can provide rapid alarming and control from small to large networks. For example, power and sensor status could be communicated quickly, inconspicuously, and securely between an emergency operation center and a nuclear facility. With ElecNet, sensors are embedded into electrical devices such as light switches, electrical outlets, and circuit breakers. These electrical devices are networked together so that sensor data from devices and circuits can be monitored and summarized elsewhere. Elecnet's many diagnostic capabilities include monitoring circuit loads, detecting arcs, and sensing fire and heat. The system also has microprocessor intelligence that allows alarming and automatic control to be incorporated into the system.

Prototypes of Elecnet electrical outlet and switch.

The Impact: Safer and More Efficient Electrical Networks

Effective monitoring and networking of electrical devices and circuits can facilitate earlier detection of problems and prevent accidents or equipment damage. The ElecNet system can alert users to problems, or it can actually shut down a circuit or outlet to prevent injury, death, or equipment damage. Since ElecNet has embedded intelligence, it can automatically decide to cut off power to a device or circuit when it is not required to improve electrical efficiencies. Elecnet's networking and embedded intelligence abilities allow data to be moved and reported in rapid and meaningful ways.

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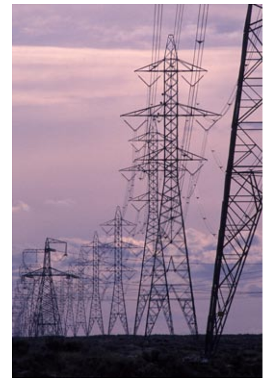
High-Temperature Superconductors

The Challenge: Upgrading the Reliability and Efficiency of the Nation's Electric Power Infrastructure

Ten percent of electricity generated in the U.S. each year (300 million kilowatt hours) is lost due to resistance of the copper and aluminum wiring currently used to transmit power across the nation's electrical grid. The energy lost is enough to supply the combined energy needs of New Mexico, Arizona, California, and Oregon. Superconductors, materials that have no electrical resistance when cooled with liquid nitrogen, can carry up to 100 times the electricity of ordinary copper or aluminum wires of the same size. These materials can be used in many electric power applications, such as transmission lines, industrial motors and generators, fault-current limiters, and transformers. The key to applying superconductivity to energy security is developing a strong and flexible high-temperature superconducting wire capable of carrying large currents in magnetic fields. At Los Alamos, this objective has led to two parallel efforts that focus on two different superconducting compounds known as BSSCO and YBCO.

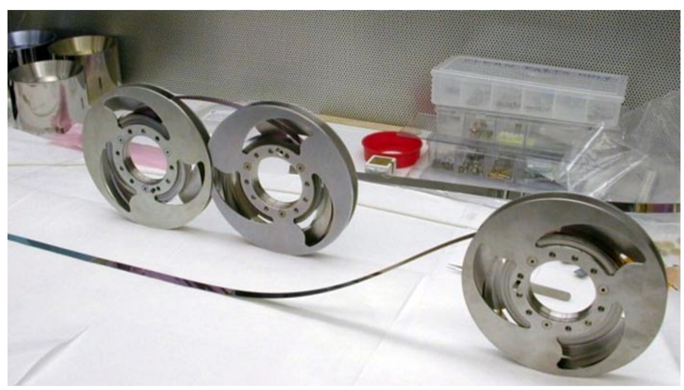


Electrical transmission lines are one of the many uses of high-temperature superconductors.

Los Alamos Innovation: Advancing Superconductor Technology for Practical Application

The first technique to yield good superconducting wire was the oxide-powder-in-tube method in which oxide powders of BSSCO are loaded into silver or silver alloy tubes, sealed, and then drawn or extruded into round wire. The round wire is then thermally processed to form a superconducting composite, or it is further rolled to produce a flat tape which is then thermally processed to produce a superconductor. Most of the conductors produced with the BSCCO materials are made in the tape form. To date, the only practical, long lengths (>1 km) of superconductors have been made with BSCCO materials. These conductors are closer to commercialization than the YBCO conductors.

YBCO conductors, known as "coated conductors" or "second generation" wires, promise better performance in high magnetic fields, higher temperature operation, and lower cost compared to BSCCO wires. However, the drawing and rolling technique for producing BSCCO wire does not work well for YBCO wire, so Los Alamos has developed new techniques to produce practical lengths of YBCO wire. The new techniques rely on ion beam assisted deposition and pulsed laser deposition to deposit thin films of YBCO on a strong and flexible substrate.



Reels of superconducting tape that have a current density 100 times that of copper wire.

To advance these technologies and move them quickly out of the laboratory to the electric grid, Los Alamos established the Superconductivity Technology Center, a user research facility that coordinates a multidisciplinary program in research, development, and technology transfer in collaboration with industry, universities, and other national laboratories. Research areas include wire and system development, powder synthesis, processing of tapes and coils, deposition of thin and thick films, characterization of micro-structural and superconducting properties, power cryogenic engineering, and fabrication of prototype devices. Through industrial collaborations, more than 1,000 km/year of BSSCO wire is now being manufactured.

The Impact: Unprecedented Electrical Efficiencies and Cost Savings

Superconductivity will have a dramatic economic impact. The electricity saved by superconductor cables could equal $4 billion per year. In comparison to conventional technologies, superconductivity power equipment will typically be half the size and have half the energy losses. High-temperature superconductors will dramatically enhance the nation's energy security by increasing the efficiency and reliability of the electrical power grid.

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Superconducting Fault Current Limiters

The Challenge: Preventing Power Outages and Damage from Current Surges

Lightning strikes a transmission tower, high winds blow down a tree, a truck runs into a power pole, heavy ice pulls down power cables, a careless builder digs up underground power lines, an unfortunate squirrel is in the wrong place at the wrong time; all of these are familiar and common occurrences. And all of them can cause current surges, or "fault currents," to travel through the electric grid at up to 20 times the normal operating current and cause blackouts. The result, in addition to the temporary inconvenience of being without power, is billions of dollars in damage to utility, industrial, and homeowner equipment, and in lost business time and manufacturing production. In over a century of electric power, no economical and efficient current surge suppressor, or fault current limiter, has been devised for the electric power grid. Superconductors are poised to change that.

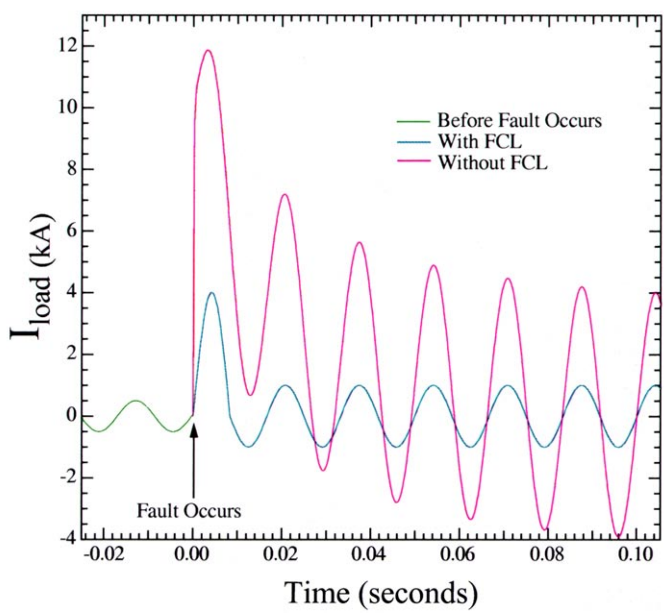
Lightning is only one of many causes of fault currents that result in blackouts and costly damage to electrical equipment.

Los Alamos Innovation: Applying Superconductivity to Fault Current Limiter Technology

A perfect fault current limiter (FCL) should (1) have zero impedance during normal operation; (2) increase greatly in impedance when excessive current is present; (3) rapidly detect surges and act instantly; (4) allow immediate return to normal operation after the fault has cleared; and (5) be fully automatic, reliable, and inexpensive. These are precisely the characteristics of high-temperature superconductors. Because superconductors normally have zero impedance, a superconducting FCL would be "invisible" under regular operating conditions and not affect efficiency like some FCL devices currently in use. However, the unique properties of superconducting materials cause them to become naturally more resistive when higher currents are present. Unlike circuit breakers, which may not open before damage has occurred and may not reclose if the fault current was too severe, a superconducting FCL will instantly react to control a fault current and then return to normal operation just as quickly after the fault has passed.

Los Alamos National Laboratory has long been an international leader in the science and technology of high-temperature superconductors and has already successfully applied its expertise to the control of fault currents. In collaboration with General Atomics, IGC-SuperPower, and Southern California Edison, Los Alamos has developed and successfully tested a 15 kV fault current controller that combines advanced power electronics with the world's largest superconducting solenoids. The Laboratory is now working with IGC-SuperPower to create a much simpler, more compact, and less expensive superconducting FCL that can be widely dispersed throughout utility transmission lines. Los Alamos will play a key role in materials characterization, cryogenic engineering, prototype design and fabrication, computer modeling of system performance, and device testing.

The graph shows how superconducting fault current limiters prevent severe spikes following a fault event and stabilize the current rapidly.



The Impact: A Reliable, Uninterrupted Power Supply

Superconducting fault current limiters will greatly increase the efficiency and reliability of the nation's electrical power grid. They will improve safety, enhance power quality, and reduce damage to utility and customer equipment. They will also defer the urgent need for costly transmission and distribution system upgrades by protecting the current aging systems.

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